LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-JRNL-637717

Developing a New Paradigm for Nuclear Test Monitoring with the Source Physics Experiments (SPE)

C. M. Snelson, R. E. Abbott, S. T. Broome, R. J. Mellors, H. J. Patton, A. J. Sussman, M. J. Townsend, W. R. Walter

May 29, 2013

EOS, Transactions of the American Geophysical Union

Disclaimer

Developing a New Paradigm for Nuclear Test Monitoring with the Source Physics Experiments (SPE)

by

Catherine M. Snelson[1], Robert E. Abbott[2], Scott T. Broome[2], Robert J. Mellors[3], Howard J. Patton[4], Aviva J. Sussman[4], Margaret J. Townsend[1], and William R. Walter[3]

For submission to

EOS, Transactions of the American Geophysical Union

May 2013

[1] National Security Technologies, LLC
P.O. Box 98521, M/S NLV101
Las Vegas, NV 89193-8521

[2] Sandia National Laboratories
Albuquerque, NM 87185

[3] Lawrence Livermore National Laboratory
Livermore, CA 94550

[4] Los Alamos National Laboratory
Los Alamos, NM 87545

Developing a New Paradigm for Nuclear Test Monitoring

with the Source Physics Experiments (SPE)

by

Catherine M. Snelson, Robert E. Abbott, Scott T. Broome, Robert J. Mellors,

Howard J. Patton, Aviva J. Sussman, Margaret J. Townsend, and William R. Walter

A series of chemical explosions, called the Source Physics Experiments (SPE), is being conducted under the auspices of the U.S. Department of Energy's National Nuclear Security Administration (NNSA) to develop a new more physics-based paradigm for nuclear test monitoring. Currently, monitoring relies on semi-empirical models to discriminate explosions from earthquakes and to estimate key parameters such as yield. While these models have been highly successful monitoring established test sites, there is concern that future tests could occur in media and at scale depths of burial outside of our empirical experience. This is highlighted by North Korean tests, which exhibit poor performance of a reliable discriminant, m_b:M_s (Selby et al., 2012), possibly due to source emplacement and differences in seismic responses for nascent and established test sites. The goal of SPE is to replace these semi-empirical relationships with numerical techniques grounded in a physical basis and thus applicable to any geologic setting or depth. The need is particularly urgent at low yields and/or large scaled depths where existing explosion models are known to diverge from each other (e.g., Rougier et al., 2011). Preliminary results from the initial SPE shots indicate that revisions to our existing models are needed (Ford and Walter, 2013). Ultimately, the SPE seeks to develop a validated and robust predictive capability that will enhance the ability to model and characterize low-yield nuclear tests anywhere in the world. The SPE is distinguished from past and present-day experiments, both nuclear tests conducted previously in Nevada and ongoing chemical experiments, as it combines advanced first-principle computer simulations with field experiments in an iterative fashion, including pre-shot predictions. These predictions are then compared with observed data. A comprehensive program of study afforded by SPE is aimed at advancing the physical understanding of source phenomenology, near-field wave propagation, coupling of energy into the seismic wavefield, and generation of shear waves. The SPE addresses a recommendation of the National Research Council report (NRC, 2012) to "…renew and sustain investment in seismic R&D efforts to reap the reward of new…source models…to enhance underground nuclear explosion monitoring, regardless of the status of CTBT ratification."

The greatest challenge to physics-based monitoring is to develop comprehensive models for explosion-generated *S* waves. Such models provide insights into the causes of source asymmetries, not readily observable from *P* waves. They should work under a range of emplacement conditions and source media and should be able to predict *S*-wave amplitudes for broad frequency bands. One promising research area is to develop source models radiating *S* waves (as well as *P* waves) from rock damage of the source medium. Such damage occurs promptly in the immediate vicinity of the explosion under compressive stresses. Later in time after the shock waves encounter the nearby Earth's surface and reflect off this boundary, material failure can occur under tensile stresses distributed over a volume located above the explosion. Data acquired on SPE seeks to characterize source medium damage for normal- and over-buried explosions and for emplacements in virgin and conditioned rock where differences in seismic radiation from rock damage are anticipated.

Source Physics Experiments for Model Validation

The chemical explosions and their technical objectives for SPE phase I are listed in Table 1. Two additional phases, one in geology to be determined with material properties contrasting those of Phase I and one at seismogenic depths (~1 to 2 km based on well-constrained earthquake locations), are planned, with all three phases taking place in Nevada; this article focuses on phase I activities.

[Table 1]

For phase I, all explosions are planned to be conducted in granite in the same emplacement hole. Geological and geophysical site characterizations will provide data to support first-principle computer simulations and modeling of ground motion data. An important goal is to validate the models used for simulations of near-field data and to relate near-field phenomenology to far-field observations.

Field Data Acquisition and Site Characterization

A comprehensive set of strong-motion and seismo-acoustic instrumentation is deployed for the SPE. Data acquisition systems include high-sample-rate three-component accelerometers in boreholes drilled within 10s of meters of the source and on the Earth's surface for recording spallation, five radial lines of seismometers and infrasound sensor arrays. The seismometer deployment consists of 4.5-Hz geophones spaced every 100 m out to 2 km and broadband instruments farther out. Selected sites are equipped with rotational sensors and accelerometers. Infrasound sensors are installed at distances of ~300 m and as distant as 7 km. Continuous data are recorded for a subset of the surface sensors in order to record local earthquakes and noise for correlation studies. Records at longer distances are available from the permanent University of Nevada, Reno seismic network.

Site characterization includes detailed geologic studies of the test bed (Townsend et al., 2012) and material property measurements of the granite from core samples and of material within fault zones using standard and custom laboratory tests. Gravity surveys showed changes in apparent near-surface density after SPE-2. Cross-borehole seismic tomography and vertical seismic profiling utilized two sets of two boreholes within 40 m of surface ground zero and imaged low wave speeds in the subsurface after SPE-2 and SPE-3. Light Detection and Ranging (LIDAR) surveys done within 24 hours before and after SPE-2 and SPE-3 indicate a permanent ground displacement of up to several centimeters aligning with fractures mapped at the surface. All of these surveys suggest a damage zone due to conditioning of the granite medium by the shock waves and may help understand the generation of *S* waves.

Summary

The SPE will advance our understanding of the explosion source, leading to improved predictions of seismo-acoustic waveform responses in support of source discrimination and yield estimation at low yields. Geological and geophysical characterizations of the SPE site provide data to support first-principle computer simulations and modeling of ground motion data collected over a wide distance range. The new validated source models will enhance the U.S. capability to monitor nuclear explosions. The vast majority of data acquired under the SPE program is unclassified/unlimited, and subject to a 2-year hold similar to the policy of the National Science Foundation. Please contact Dr. Catherine M. Snelson, SPE Test Scientist (snelsocm@nv.doe.gov) for further information.

Acknowledgments

The SPE would not have been possible without the support of many people from several organizations. The authors thank NNSA, the Office of Defense Nuclear Nonproliferation Research and Development, and the SPE working group, a multi-institutional, interdisciplinary group of scientists and engineers.

This manuscript (DOE/NV/25946--1726) has been authored (CMS and MJT) by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy (DOE). The U.S. Government (USG) retains, and the publisher, by accepting the article for publication, acknowledges that the USG retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for USG purposes. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for DOE's NNSA under Contract No. DE-AC04-94AL85000 (REA and STB). RJM and WRW performed work for Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344, HJP and AJS for Los Alamos National Laboratory under Contract No. DE-AC52-06NA25396, both with the auspices of the DOE.

References

Ford, S. R., and W. R. Walter (2013). An explosion model comparison with insights from the Source Physics Experiments, *Bull. Seism. Soc. Am.* (in press).

National Research Council (2012). The Comprehensive Nuclear Test Ban Treaty: Technical Issues for the United States, The National Academies Press, Washington, D.C., 204 pp.

Rougier, E., H. J. Patton, E. E. Knight, and C. R. Bradley (2011). Constraints on burial depth and yield of the 25 May 2009 North Korean test from hydrodynamic simulations in a granite medium, *Geophys. Res. Lett.* **38**, doi:10.1029/2011GL048269.

Selby, N. D., P. D. Marshall, and D. Bowers (2012). m_b:M_s event screening revisited, *Bull. Seism. Soc. Am.* **102**, doi:10.1785/0120100349.

Townsend, M., L. B. Prothro, and C. Obi (2012). Geology of the Source Physics Experiment Site, Climax Stock, Nevada National Security Site, National Securities Technologies, LLC, Report # DOE/NV/25946-1448, March, 707 pp.

Table 1: The SPE Chemical Explosions and Their Technical Objectives

Shot Name	DOB[a]	SDOB[b]	Yield[c]	Origin Time	Short Description and Scientific Basis
SPE-1	54.9	980	87.9	3 May 2011 22:00:00.01136	Initial ~Green function (GF) shot in a simple geology Simulation capability R&D for non-isotropic effects
SPE-2	45.7	363	997	25 October 2011 19:00:00.011623	Increase shot size to record signals to 100km Investigate depth of burial (DOB) effects with SPE-5 & -6
SPE-3	45.8	376	905	24 July 2012 18:00:00.44835	Investigate damage zone effects relative to SPE-2
SPE-4	99[d]	TBD	TBD	TBD	Minimize spall, ~GF for SPE-5 DOB relative to SPE-1
SPE-5	84[d]	TBD	TBD	TBD	Increase shot size to record signals to 300 km
SPE-6	30[d]	TBD	TBD	TBD	DOB investigation with SPE-2 & -7, middle depth
SPE-7	15[d]	TBD	TBD	TBD	Final granite SPE, standard DOB for nuclear test shot

All shots to be conducted in hole U-15n; 37° 13’ 16.30” North 116° 3’ 39.12” West

[a] Depth of burial (DOB) in meters to the center of the charge

[b] Scaled depth of burial (SDOB) in m/kT$^{1/3}$; equals DOB/(2xYield)$^{1/3}$; yields of chemical explosions are multiplied by a factor of two in order to compute the approximate nuclear equivalent SDOB; kT is kilotons.

[c] Yield in kilograms, TNT equivalent

[d] Planned